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Water Balance in Urban Areas

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Abstract. Hydrological characteristics of urban area are heavily modified related to the natural catchments. Higher part of paved areas causes faster runoff process, the travel time of rainwater is much shorter, as well as the runoff volume is bigger than in natural areas. Sewer network transports higher storm water volume in shorter time: this causes higher hydraulic load on the sewer network and following CSO. Important role in this process play also anthropogenic influences. These significantly change the water balance in urbanised catchments with addition of new water (and pollution) sources or with water transfers between particular hydrological subsystems (both natural and artificial hydrological subsystems – water supply network, sewer network). Because of these reasons, it is desirable, that these negative influences will be reduced to minimum. The goal is to achieve the hydrologic characteristic of the urban catchments alike the characteristics of the natural catchment. Paper present results of a cause study, expressed in form of a system chart of the water balance. Analysed urban area has very complicated relations between particular subsystems (high exfiltration rate from the water supply network as well as high infiltration rate into the sewer network, interactions with surface and underground water). Hydrological function and impacts of particular system elements will be analysed as well as different possible management scenarios. Important parts of the analysed problems are not economical and financial aspects only, but also technical and environmental aspects regarded from the point of view of the integrated water resources management. Last but not least are also very important technical impacts, which can prevent efficient and safe operation of the water supply and sewer networks.

1. Introduction

Entry of human activities in the natural hydrologic cycle significantly disturbs not only quantitative but also qualitative parameters of the natural hydrological cycle. This concerns not only the environment of cities, but also the wider area, regions or parts of the continents. The natural hydrologic processes in urbanized catchment are significantly altered due to human activity. Construction activities on this catchment usually result in high proportion of impervious surfaces that prevent natural infiltration of rainwater, but also reduce evaporation (evapotranspiration). Storm water runoff from paved surfaces, flows in most cases to the public sewer network and water is transferred and discharged by a network out of urbanized area. Rapid runoff, however, leads to an extreme increase of the discharge, so part of this water hydraulically overflows to the recipients.

These changes are of course also influencing the hydrological balance of an urban catchment. In the literature [1] are examples of the annual balance of natural and urbanized basin, an overview of the balance is described on Figure 1. It should be noted that the figures presented in the charts in this literature can be considered as indicative, respectively as average values and in specific cases of urban catchments the volumes can be quite different. Fairly good overview of the various studies of the hydrological balance of urbanized areas can be found in paper [2]. According to the results reported, for example evaporation in different locations can reach values from 17 to 71% of the annual total volume of water in the examined urbanized catchment, surface runoff from 29 to 76%, infiltration from 0 to 28%. An interesting study is an analysis of the hydrological balance of the urban water cycle, published by Carlsson and Falk [3] for the territory of urban areas in Sweden.

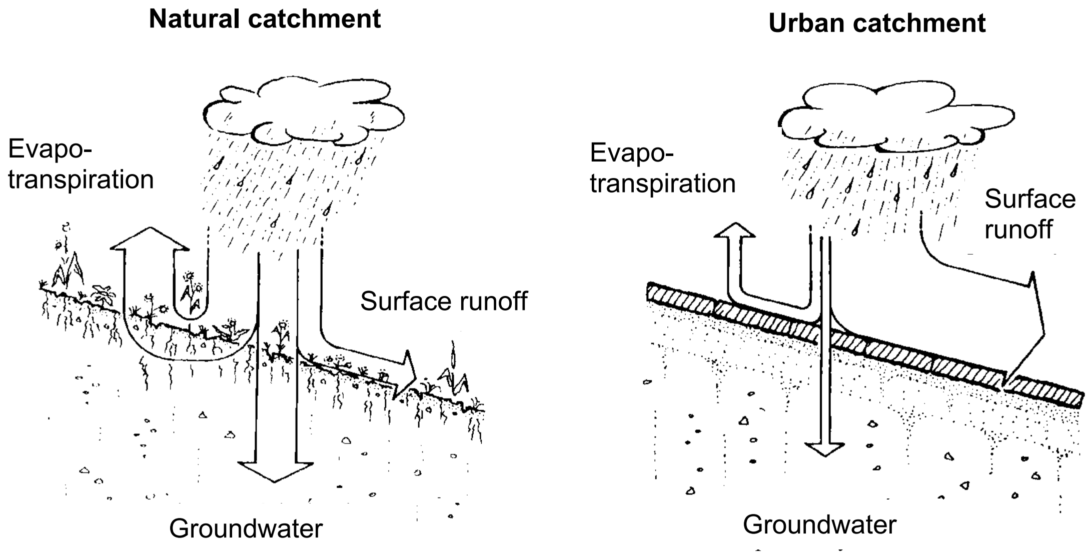

Figure 1. The annual volumetric hydrological balance of a natural catchment (with vegetation cover) and an urbanized catchment (central part of the city) [1]

The foreign studies mentioned above are certainly interesting documents. But in the specific conditions of the Slovakia can be the hydrological balance of urbanized catchment significantly different. As a significant factor, which may cause substantial differences we particularly consider the infiltration into sewer systems, as well as water discharge of extraneous water (private water wells, drainage systems) into the sewer network, as well as lost springs and streams, captured in combined sewer systems [4]

2. Background

In the literature, we could find many studies and scientific articles dealing with issues of urbanized area hydrology. Almost all papers without exception refer to the long-term strategic objective, which is to approach the hydrological characteristics of urban catchment to the natural catchment. With simple analysis of Figure 1 could be stated, that it is necessary to reduce the volume of surface runoff and increase the rain water transfer into the groundwater. As a starting point, respectively one of possible ways to solve this problem, the principle was adopted: to disposal the rain waters in place of their origin, ie. on the urban catchment. As the main process to be used within this concept, the infiltration of low polluted water from surface runoff into groundwater has been considered.

From this point of view an interesting paper is the study of Japanese authors [5], which was performed on which relatively extensive Ebi river basin (27 km^2). This river was analysed using two scenarios of urbanization: with and without the infiltration trenches focusing on the hydrological regime of the river network and with regard to the occurrence of maximum flows and flooding risk. The scenarios are built on assumptions of urbanization in the basin since 2035, and the technical rainwater infiltration feasibility was taken into account. The results of this study according the authors clearly demonstrate the need, respectively advantages of drainage facilities use regarding the water catchment.

This approach also will allow a sustainable development preserving the hydrological characteristics of the original river before urbanisation, despite of a relatively significant urbanization increase.

3. Case study Pezinok

For a complex analysis of the hydrological balance, we decided to perform an analysis of the hydrological balance of a city in Slovakia. The town of Pezinok was chosen, because of very interesting solutions regarding the water balance and sewerage disposal.

The river network around the town of Pezinok consists of streams running down the eastern side of the Small Carpathian Mountains. Their runoff conditions are characterized by irregularities during the year and in the course of the longer hydrological period. The quantity and the areal distribution of precipitation are subject to the altitude and orientation. In most areas of the district, the average precipitation ranges from 600 to 700 mm / year.

The most significant creek in the area of interest is the Blatina creek. This creek is in hydrological order 4-21-15-002, its catchment area has 18.760 square kilometres and the total catchment area of 37.852 km^2. The Blatina creek in river chainage 11.30 – station Pezinok had in 2008 the average annual discharge Qa= 0.079 $m^3.s^{-1}$. Minimum monthly flow was recorded in August (0.028 $m^3.s^{-1}$) and maximal in December (0.219 $m^3.s^{-1}$).

Rated territory belongs to the hydrogeological area MG 055 - crystalline and mesozoic area of the south- east part of the Pezinok's part of the Carpathian Mountains, into the sub-rayon, which consists of quaternary alluvial deposit cone floated from crystalline. The proluvial cone has a continuous horizon of groundwater. The groundwater level is mainly dependent on rainfall and the permeability of the ground. The direction of groundwater flow corresponds to the neogene bedrock surface gradient, ie. that the territory does not drain directly to Blatina creek, but the direction of flow is a stream which flows to the creek, which flows out from the dam, situated above the city. Based on empirical relationships we can assume the coefficient of permeability value of the gravel soils of the order of 1.10^{-5} to 1.10-6 $m.s^{-1}$.

In the City of Pezinok is water supply system, which supplies drinking water to almost the entire territory of the city. For the water supply purposes are fully used the available local resources. Because of the insufficient capacity of these water sources the city of Pezinok has to be supplied by the water sources, located at relatively far outside of the city area (water resources Šamorín, Podunajské Biskupice, approx. 20- 28 km). Connection rate the area is according to the operator around 96%, which is more than the national average (about 86%) and there are total 20,865 inhabitants served with water supply. Problem of the existing water supply network is relatively high age of the network pipes (mainly steel pipes), relatively high failures occurrence, what causes high water losses rate in the supply network. [6, 7]

In the City of Pezinok combined sewerage network with an existing wastewater treatment plant (WWTP) exists since 1970. The WWTP was located in the southern outskirts of the city. The problem of the sewer network in the city is also its relatively high age and high proportion of infiltration water into the sewer network [6, 7]. A significant change in the sewerage system come into being at the end of May 2009: The operator stops operation of the existing WWTP in the town of Pezinok and all sewage water is pumped by pressure main to the central wastewater treatment plant in Bratislava – Vrakuňa (about 18 km), which has currently quite large unused capacity. Instead of the WWTP there is currently only sewage pumping station and a temporary accumulation tank for the waste water for the storm water storage or for the event of pump failure. Removal of the old, overloaded and malfunctioning wastewater treatment plant will probably improve water quality in the recipient Blatina in the near future. On the other hand, the mentioned WWTP was not only pollution source, but also substantial tributary for the creek Blatina (average annual flow in 2008 was in the creek about 79 $l.s^{-1}$, the flow of treated water from WWTP Pezinok was about 100 -130 $l.s^{-1}$).

Based on available data, we created a detailed scheme of the hydrological balance and water transfers in the town of Pezinok, which includes also volumes of water transported in and out of the city area by the water infrastructure (water supply, sewerage). This balance is shown on Figure 2. At this point, it should be noted that we received the water volumes from the water infrastructure operator (Bratislava waterworks company, a.s.) and for the quantities of water from natural sources we used available and accurate hydrological data. Where no such data were available, water volumes were determined based on expert estimates.

4. Risks

The principle of water balance is the rule, that the volume of water is constant, therefore water goes not lose and it only changes its place of occurrence. If part of the water from surface runoff will be transferred into the infiltration facilities, a reduction of surface runoff will be achieved. However, the implied question will be: what happens with the increased amount of underground water? Logical (=hydrological) answer is, that there will be groundwater flow increase towards the surface water, which acts in urban catchments as underground drainage, but only in cases where the basin is with a sloping surface and surface water (creeks, rivers) are present in the urbanized area.

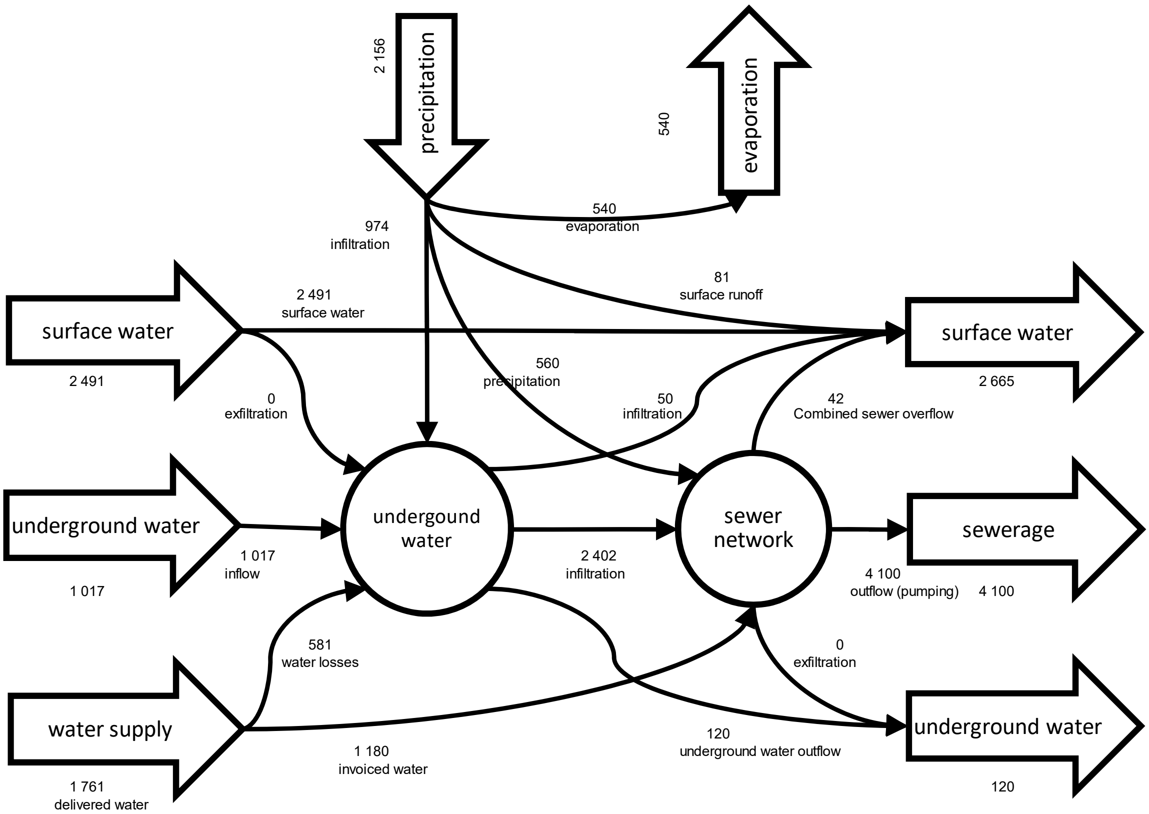

Figure 2. Water balance of Pezinok town area (values are given in thousands of m^3 per year)

However, if the urbanized area is relatively flat and there is a sparse hydrographical network, it can be assumed that in the urban areas a relatively stable level of groundwater is established, particularly stabilized by leaky sewer systems, which acts in the urbanized area as a drain system. This level of groundwater was considered for many years as a natural level and lot of constructions were adjusted to this underground level on the site, particularly in terms of waterproof insulation of underground spaces, buildings and other infrastructure. Groundwater level rise, which may be due to the increased surface runoff infiltration, will probably result in the increase of infiltration into the sewer network. [8] The amount of the infiltrated water can be predicted, but there are still important factors, which are in our case unknown [9, 10]

Logical step of the sewer network operator is a rehabilitation of the sewer network and its sealing. In aim to reduce the water infiltration into the sewer network, but this will also increase the groundwater level, since the sewer network will be sealed and will no longer work as a drainage system for the underground water. This may be followed by further infiltration increase into the sewer network at the upstream sewer network sections and in particular on household connections, but probably also by unauthorized water inflows - particularly small drainage systems, built to protect the objects and buildings against the groundwater because of higher groundwater levels.

The above scenario looks in some respects very unlikely, but the cause of increased groundwater levels may not only be increased surface runoff water infiltration. It can also be due to increased precipitation (this happens indeed in the extremely wet years) and the fact is that certain aspects and events described above are already happened in the past at various locations.

5. Solutions

The solution of this difficult situation can be technical measures aimed to achieve the original hydrological conditions. These measures may be aimed in two directions:

1. In cases where it is necessary, it is appropriate to reduce the amount of infiltrated water by using other means of surface water runoff disposal, e.g. evaporation support measures (green roofs, detention tanks), elimination of illegal outlets, the drainage
2. Groundwater level decrease by other means, then infiltration into leaky sewer network, for example with other drainage systems

In the first case we have to ensure, where necessary, that we will infiltrate to the underground water only such quantity of surface runoff water, which does not negative affect the water balance and groundwater will not endanger buildings located in urban areas. The solution may be to support the evaporation with green roofs. It may be also the storage of runoff water and its re-use, e.g. for irrigation of urban green areas, recharge water in fountains, and watering the streets. It is also possible to use rainwater as process (service) water in industry, respectively also in households (toilets flushing or washing). A separate group of measures to evaporation support in cities is to establish water bodies, which may serve as an open air stormwater tanks.

Naturally, there must be also effort of the infrastructure operator to eliminate illegal drainage inlets to public sewer system, even though this is quite tedious and difficult task, requiring household's connection inspection in combination with monitoring of the drinking water consumption and wastewater production in dry weather period.

The second group of measures (in aim to decrease groundwater level in urban areas) may include measures to reduce groundwater levels by point, line or area drainage. Construction and operation of new drainage facilities for the underground water decrease will be probably financially very expensive and will require different restrictions for residents; therefore, this method is appropriate only in specific parts of the cities. However, we believe that in some cases it would be possible to use the existing drainage systems were built, e.g. during the construction of buildings or the construction of certain utilities.

An interesting way how to resolve this situation was shown in the town of Liptovský Hrádok within the project "Environmental improvement of the Liptov region", co-funded by the EU Cohesion Fund (former ISPA). In the city a new sanitary sewer system was build, and the old and leaky combined sewer system was reclassified to a storm sewer network, so a complete separated system was established. Thus, old and leaky sewer system diverts water from surface runoff, and because it was not sealed, it works as a drainage system for groundwater.

Infiltrated underground water has typically very low pollution level, so we can assume that in most cases, that the state water authorities will not have objections to their direct discharge into surface water (recipients) without further treatment (but some mechanical pre-treatment will be required for rainwaters).

6. Conclusion

The paper deals with the quantitative water balance of an urban catchment. The overall objective of surface runoff management is to achieve such hydrological characteristics of the urbanized catchment, which are similar or equal to the natural catchment. It is mainly an effort to reduce the velocity and volume of surface runoff and the effort to increase the groundwater build-up, in other words to increase infiltration of surface runoff by disconnection of paved surfaces in urban areas and infiltration of the surface runoff water into the groundwater. The question is if such an increase of groundwater volume, which also leads to groundwater levels increase is acceptable and appropriate for urban catchment area. On the one hand, it represents an approximation to the natural conditions, but on the other hand, it partially changes long-term steady hydrogeological regime of groundwater flow, which can cause considerable problems for all buildings, located on urbanized area. Moreover, it is likely to be assumed that the increased amount of underground water ends in the sewer network, whether as infiltrated water, or as illegal inflow of the drainage water.

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